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Dialogues on Architecture #6

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Abstract

Dialogues on Architecture, published in various issues of Spool CpA, is a series of dialogues between researchers and practitioners, who are embracing the intellectual model of high technology and are involved in its advancement and application in architecture. Dialog #6 presents discussions risen during an online symposium on challenges of the Architecture, Engineering and Construction (AEC) industry, which is facing a threefold challenge involving the (i) digital transformation of all design and planning processes, (ii) automation of construction processes, and (iii) reconsideration of energy, process, and material use.

These challenges involve issues with respect to productivity, scalability, safety, labour skill shift, and environmental impact. Acknowledging that there is a particular urgency in transferring effective solutions from research to building practice to meet significant carbon reduction goals by 2040, the one-day symposium organized as an online event in 2022 [1], Human-Robot Interaction for Post-Carbon Architecture (HRI4PCA), was an opportunity to make an inventory of current tendencies in autonomous construction and human-robotic interaction in architecture. It aims at affirming and/or challenging research agendas in the domain of architectural robots.

Keywords

Human-robot interaction, post-carbon architecture, autonomous construction, AI

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1 Link to HRI4PCA announcement: http://www.roboticbuilding.eu/2022/03/09/symposium_hri4pca/

Dialogue

Mirco Becker (MB): When we started drafting the call for the Human-Robot Interaction for Post-Carbon Architecture symposium in 2021 we had a few questions in mind to frame the topic. Let's look back at these questions and reflect on how they were addressed during the symposium as well as by publications and projects implemented shortly thereafter. We start with the question addressing climate change, which by now seems to be woven into almost any project and call. Very simply, we asked: What are the fundamental research questions for framing post-carbon autonomous construction?

Henriette Bier (HB): Some of the considerations concern material, energy, and process efficiency focusing on (i) how to develop sustainable and low-carbon construction materials that minimize embodied carbon emissions and environmental impact while maintaining structural integrity and performance, (ii) how to optimize energy efficiency in construction processes by autonomous manufacturing, assembly, and operation of buildings, (iii) how to automate construction tasks, optimize resource utilization, and reduce energy consumption while ensuring safety, quality, and precision in construction. These questions were explored in the symposium from synthesizing big data to semi-/ autonomous AI-driven fabrication with robots (Fig. 1) envisioned as 'heterogeneous robot fleets on construction sites' providing a blueprint for the next-generation building in which robotic hardware development is part of the overall design process and its output.

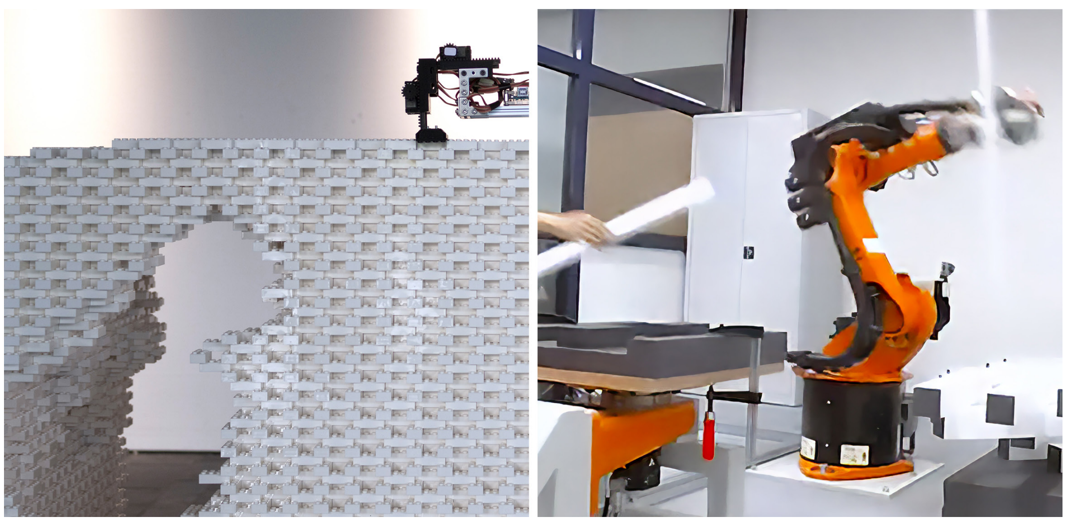

FIGURE 1 Computer-generated toolpath (left) and 3D printed prototype (right) by Vertico 3d printing specialists (©RB lab, TU Delft).

MB: Digital technologies in architecture have accumulated an extensive body of research and methods over the past 20 years. Various topics accompanied the development of the digital in architecture including geometry, material and fabrication, and robotics. For the symposium, we wanted to shed light on a particular triplet by posing the question: What are the interdependencies between machines, humans, and materials? Are we at a point where we can identify promising research and projects emerging from this question?

HB: Various speakers [1] from the EU, Australia, Canada, and the US presented research developed at TU Delft, Leibniz University Hannover, TU Darmstadt, ETH Zürich, University of Stuttgart, the Bartlett (UCL),

1 Link to HRI4PCA speakers: http://www.roboticbuilding.eu/hri4pca-speakers/

RMIT, McNeel, University of Toronto and Boston Dynamics. The themes ranged from synthesis of big data to human-robot collaboration, mobile and miniaturized robotic approaches, and robotic spaces, structures and building systems. All speakers acknowledged that robots, humans, and space are increasingly intertwined with robot systems evolving into 'robotic spaces, structures and building systems' that rely on AI-supported semi-/ automated processes.

MB: Let's look again at the question of material. Our attitude towards material is fundamentally challenged. We need different materials ideally carbon-positive ones, we need to reuse and recycle materials that are already in the cycle, and we need to invent strategies to disassemble and reassemble buildings constructed today so the material stays in the cycle far longer than the lifespan of a single building.

HB: Recycling is a big concern that we have been addressing in the Robotic Building (RB) lab at TU Delft by reprocessing reclaimed wood. Identifying which strategies are more efficient, ranging from reassembling to reprocessing, is one of the challenges that one of my PhD students is now investigating. There is also the aspect of design for circularity as Oliver Tessmann presented: a novel construction system made up of interlocking dry joint SL blocks. Such construction systems fully assembled and reassembled by AI-guided robots would stay in the built environment over a very long period of time multiple times the life span of a single building.

MB: The work presented by Daniela Mitterberger is especially forward-looking. She presented novel human-augmentation strategies and tools needed for human-machine collaboration to perform non-standard fabrication tasks at full architectural scale (Fig. 2) This might also lead to a very different understanding and use of material. Such machine-augmented construction processes have the potential to not only execute the defined task or target but also to give individual insight into material construction logic and its environmental performance.

FIGURE 2 Co-Corporeality – eye tracking device to control machines (© Zita Oberwalder).

Against the backdrop of climate change the responsibility of the building sector is undisputed. Still, it is not clear at all how and when we can make a significant contribution to mitigating CO2 expenditure. *How do different implementation timeframes define strategies for transferring research, as for instance, continuous transformation vs. leapfrogging?* With this third question we wanted to get insight into different research strategies and how they compete or complement each other.

HB: Continuous transformation focuses on making incremental improvements within the existing framework, while leapfrogging involves making disruptive innovations to achieve rapid advancement. Both strategies have their advantages and challenges, and often instead of adopting one or the other, a combination of both approaches proves to be effective.

MB: Interestingly there is a remarkable variety of novel robotic concepts beyond the industrial robot. At the symposium, we saw established legged robots like SPOT presented by Brian Rigley from Boston Dynamics. Enabling mobile robots with infinite workspace to perform building tasks has great potential in construction as confirmed by Brian Ringley, who presented new mobile modalities for more effective site management, for instance, wheeled/tracked mobile robots. By employing building autonomous navigation systems and agile mobile robots an unprecedented amount of data is captured in dynamic, human-purposed environments. The integration of geospatial hardware, 5G telecommunications, cloud computing, and emerging AI for unstructured reality capture data provides new approaches of feeding digital twins in construction. Twins are the key to establishing reality feedback loops accurately coupling the virtual and the real using heterogeneous robot fleets on construction sites.

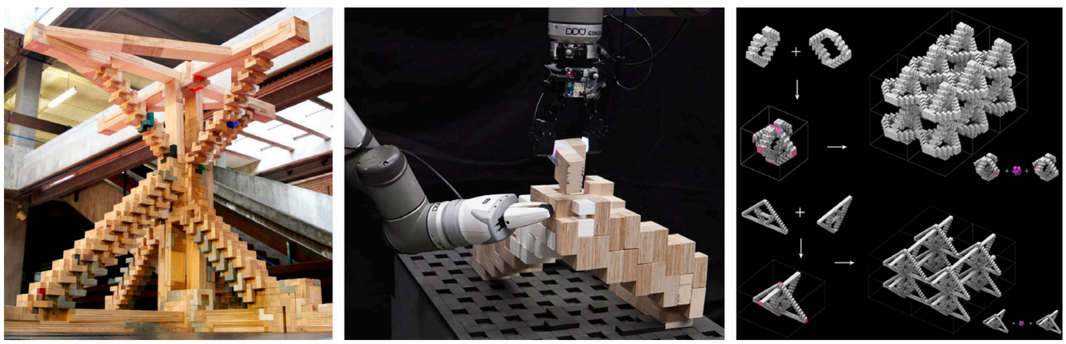

FIGURE 3 Autonomous assembly of modular systems employing AI-driven robots equipped with visio-tactile sensors implemented at TU Darmstadt.

Maria Yablonina is considering robotic hardware development as part of the overall design process and its output, as I do too. In this context, design moves beyond the design of objects towards the design of technologies and processes that enable new ways of both creating and interacting with architectural spaces. I presented the miniaturization of autonomous construction robots and material formats, which involves the design not only of buildings but building systems. Similarly, Oliver Tessmann presented autonomous assembly of modular systems employing AI-driven robots equipped with visio-tactile sensors (Fig. 3). Dry-jointed and reversible elements allow for their assembly, disassembly, and reassembly in a circular fashion. In contrast to HRI, the project shifts away from immediate collaboration. Valentina Soana develops lightweight structures with shape-changing behavior. She designs adaptive material and structural systems that can achieve multiple states of equilibrium. Robotic systems are not tools anymore but become robotic spaces, structures and building systems, opening up new interaction scenarios between humans, materials, and machine systems.

HB: In addition, Serban Bodea's research into advancing robotic coreless filament winding as enabler of mass customization of large-scale lightweight structures [2] requires acknowledgement. Lukas Lachmayer however, re-evaluates large-scale production, whether additive, subtractive or through forming, which is often realized by upscaled machinery. He highlights that while this appears the easiest way to achieve required tolerances, such production systems lack flexibility.

2 Link to AddFiberFab: https://serbanbodea.com/addfiberfab/

MB: While the programming of industrial and collaborative robots becomes ever easier and thus more accessible for designers, we also see the fundamental limits of these types of robots in terms of their use in construction. There is certainly a need for novel types of robots, but inventing robots is neither trivial nor fast. Are we at a point where we might need a new attitude towards breeding new robots? Analogous to the didactic question of the 2000s inquiring if *'every architect needs to be capable of scripting' the question now is if 'every architect needs to be a robotic inventor'*.

HB: I am a strong promoter of collaboration with computer scientists and roboticists. The architect remains the generalist, having an understanding to some degree of all aspects and relying on specialists for the implementation. I presented Design-to-Robotic-Production-Assembly and -Operation (D2RPA&O) methods developed in the Robotic Building (RB) lab at TU Delft. These link efficiently computational design with robotic production, assembly, and operation and employ a customizable multi-robot and multi-effector approach relying on Human-Robot Interaction (HRI) to facilitate effective and safe physical interaction between robots and humans implementing complex tasks.

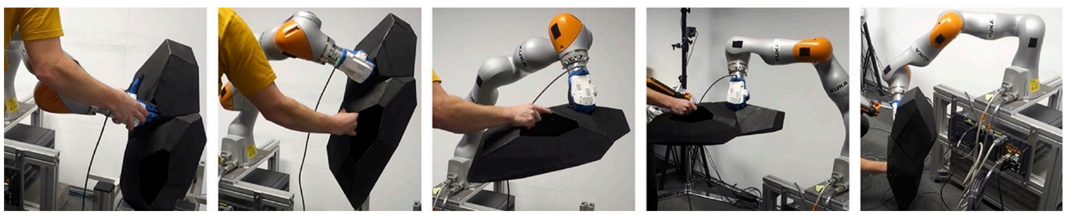

FIGURE 4 HRI-supported pick-and-place study implemented at CoR lab.

Aspects of HRI are implemented in collaboration with Luka Peternel from Cognitive Robotics (CoR) lab at TU Delft (Fig.4), who considers robots as very good at handling high physical workload and performing precise and fast movements, while humans have superior cognitive capabilities and manual dexterity. He combines these attributes in physical human-robot collaboration for construction and employs methods based on impedance control to enable compliant and safe operation. Higher-level reasoning and communication between the human and the robot are handled by an AI system based on machine learning (ML) methods and various sensory interfaces. The ultimate goal is to advance robotics in architecture while taking into consideration that more than 50% of tasks can and will be fully automated, while 45% rely on HRI, and only 5% remain in human hands.

MB: After carefully framing the call for the symposium and having invited an inspiring selection of contributors, the question is if there was any perspective or topic during the symposium which shifted the focus beyond what we anticipated.

HB: One of the research questions that we did not formulate explicitly, but was addressed by one of the speakers, Alisa Andrasek, reflected on the current synthesis of big data from a multitude of sources enabling context-sensitive and integrated systems within information-rich simulations and applications as for instance typologies synthesized with local data and computational physics, context-sensitive models for buildings and green energy infrastructure, or artificial intelligence (AI) combinatorics for increasing variability of prefabrication . Perhaps, the next symposium will focus on questions such as (i) how can machine learning algorithms be applied to big data for predictive modelling, classification, and clustering, and (ii) what are the challenges and opportunities of deploying machine learning models in architecture.